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XI.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XV. SIMPLE METHOD FOR CALIBRATING THERMOMETERS.

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Presented March 8, 1882.

The calibration of a thermometer by most of the methods in ordinary use is a tedious and somewhat difficult operation, and hence often neglected even in important work. For the purpose of supplying a method simple both in observation and computation, and at the same time accurate, the following process is described, which, although involving little that is new, has not, to my knowledge, been used before.

First, however, it is necessary to recall to the attention of observers the fact that, without calibration correction, the readings of a thermometer having a scale of equal linear parts cannot be relied upon within one or more divisions of this scale; and that thermometer makers, knowing this, almost universally space the graduation upon the tube to correspond more or less closely with the shape of the bore, as determined by previous calibration or by comparison with a standard (!) instrument. This practice is much more general than is ordinarily supposed, and has an important bearing upon the accuracy of the work done with such instruments. For the scale thus made is merely approximate, the dividing-engine or other tool being changed only at such intervals as to make the average error less than some specified amount. An inspection of these conditions will show that the calibration of such a tube and scale can be only approximate, except with corrections for the inequalities of the spacing, involving an amount of labor disproportionate to the result attained. The best makers, such as Fastré, Baudin, and others, have produced satisfactory thermometers graduated to equal volumes; but even these are not as reliable as instruments of less cost with a scale of equal linear parts, say of millimetres, supplemented by a calibration by the observer rather than an approximation by the maker.* The best form of tube for almost all work is one backed with white enamel, with an inverted pear-shaped bulb at the upper end of the capillary (a very important feature), and with a scale of equal arbitrary linear parts (0.7 mm. to 1 mm. is a suitable length for estimation of tenths) or of approximate degrees, for convenience, etched or engraved upon it.

Without reviewing here the methods proposed by various writers, it may be said that it has been the general plan to select beforehand upon the scale two points between which to make the calibration, this space being considered the "calibration unit"; the errors of these points being, of course, zero. This plan has led to unnecessary complexity in the resulting methods. Such an assumption is no more requisite in calibration after a scale has been put upon the tube, than in calibrating by the dividing-engine or micrometer before making the scale. It is obvious, therefore, that the selection of these points is wholly arbitrary, and, if used at all, one or both of them may, if desirable, be chosen after the observations with the calibrating thread have been made. The choice should be made with the view of facilitating the work. Hence the use of the observed freezing and boiling-points, upon which some methods are based, is most undesirable.

In the method which will now be given, either one or both of these points may be left to be selected, according to the combined conditions of length of thread employed, shape of the tube, and numerical convenience, after the observations with the thread have been made.

Let it be desired to find the calibration corrections for a given tube. Determinations which will give the errors of every 3 cm. of length will ordinarily be sufficient, but this must depend upon the result sought. Separate a thread of mercury of about that length. The actual length of the thread within two or three millimetres is of no consequence whatever; and hence a suitable thread can be obtained in a very short time.

Set the thread with its lower end at or near the beginning of the graduation: call the reading† of the lower end of the thread l_1, and that of the upper end u_1. Move the thread less than 1 mm. and read again, finding thus l_2 and u_2. Move the thread about 1 cm. and read l_3 and u_3. Move less than 1 mm. and read l_4 and u_4. So continue throughout the whole length of the graduation, increasing the number of settings and repeating the whole series in reverse order, if the highest attainable precision is desired. Avoid, as far as convenient, taking readings with an end of the thread apparently just at a line of the scale, as the width of the line, even in the best scales, is a source of considerable error.* If the zero point of the graduation has for any reason been selected as the first of which the error should be assumed zero, the settings may to advantage, though not necessarily, be made to extend each way from this.

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* It should be noted that thermometers intended for measurements above about 280°C. almost always contain sufficient air to render the separation of a thread for calibration difficult, if not impossible. The object of the air is that its pressure upon the top of the column may prevent the mercury from entering into ebullition.

† Tenths of a division are supposed to be read by estimation.

Then $u_1 - l_1$, $u_2 - l_2$, &c. will give a series of lengths of the calibrating thread in all parts of the tube. Before reuniting this thread to the rest of the mercury, plot points with abscissas l_1, l_2, &c., and ordinates $u_1 - l_1$, $u_2 - l_2$, &c., the corresponding lengths of thread, and draw a smooth curve through the points thus obtained. This line will give a general idea of the form of the capillary bore; and, should any parts of it show considerable irregularities, the corresponding portions of the tube should be at once re-explored with the thread.

If not already done, the point, A, upon the scale, to be used as the starting or reference point of the computation, should now be selected. In general the extreme ends of the tube are to be avoided, as more likely to have been rendered irregular or rapidly tapering in the process of making or joining on the bulbs. If the zero of the numbering is placed two or three centimetres from the bottom of the tube, it forms a desirable starting-point.

Find upon the curve the ordinate u' corresponding to the abscissa A; then with abscissa $A + u'$ find the corresponding ordinate u''; with abscissa $A + u' + u''$ find the corresponding ordinate u''', thus continuing to the upper limit of the graduation. If A is at a sufficient distance from the lower end of the graduation, find for the point with abscissa $A - w'$ the corresponding ordinate w'; as may be readily done, when necessary, by inspection of the curve, finding the ordinate, which, added to its corresponding abscissa, will give A; then with the abscissa $A - w' - w''$ find the ordinate w'', &c. These points $A - w' - w''$, $A - w'$, A, $A + u'$, $A + u' + u''$, &c., upon the graduation are the points separated by equal volumes of the capillary. When the calibration extends both ways from the zero of graduation, the readings below A should be treated in the same way as those above that point, and this case will therefore not be further considered. Select any one of these as the second point of which the error is to be arbitrarily assumed as zero, and call this B. Then

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* Some of the advantages of Neumann's method are offset by this error.

$$A + u' + u'' + \dots + u^{\text{nth}} = B.$$

There are thus n spaces of equal volume between A and B, and these correspond each to $\frac{1}{n}$th of the interval $B - A$. Hence the true reading (which, however, it is not necessary to compute numerically) at the point

A	is	A
$A + u'$	“	$A + \frac{1}{n}(B - A)$
$A + u' + u''$	“	$A + \frac{2}{n}(B - A)$
. . . .		. . . .
B	“	B
$A - w'$	“	$A - \frac{1}{n}(B - A)$
$A - w' - w''$	“	$A - \frac{2}{n}(B - A)$
&c.		&c.

And the error, obtained by subtracting the true readings as given in the right-hand column from the corresponding actual reading given in the left-hand column, at

A	is	0
$A + u'$	“	$A + u' - \{A + \frac{1}{n}(B - A)\} = u' - \frac{1}{n}(B - A)$
$A + u' + u''$	“	$u' + u'' - \frac{2}{n}(B - A)$
. . . .		. . . .
B	“	0
$A - w'$	“	$-w' + \frac{1}{n}(B - A)$
$A - w' - w''$	“	$-w' - w'' + \frac{2}{n}(B - A)$
&c.		&c.

In selecting B it might have been assumed equal to $A + u'$, thus making $n = 1$. This would somewhat simplify the calculation, and would be of equal accuracy, but is objectionable from the fact that in general this volume would differ considerably from the average volume obtained when n has a greater value (always an integer), and the resulting series of errors would assume larger numerical values.

The errors or corrections are, for purposes of interpolation, most conveniently represented graphically by a smooth curve through points with abscissas proportional to the direct readings

$$A - w', A, A + u', A + u' + u'', \text{\&c.},$$

and ordinates to the corresponding corrections.

Should it be necessary to increase the accuracy by a second calibration with a thread of different length, it is only necessary to take one of approximately an integral part of $(B - A)$, and when the final curve of error is drawn, make the error at B equal to zero, distributing the difference at that point proportionally to the scale readings among the errors at the intermediate points: in other words, to shift the axis of the second curve of error so that it shall make the error at B zero. The superposition of a second curve of error deduced from the same series of observations as the first, but using another starting-point, A' differing from A by a suitable fraction of the length of the thread used, will somewhat increase the accuracy of the result by rendering interpolation more certain, but neither of these procedures is requisite except where a very detailed study of the instrument is to be made.

This method requires for each calibration the use of but a single thread. The computation is simple, and involves a minimum of approximation. Errors of observation are largely eliminated by the number of settings made in all parts of the tube, and by the inspection of the curve of lengths, both of which operations tend in an unusual degree to detect any mistakes or minor irregularities of the capillary. It avoids the common requirement of setting the thread exactly at certain definite points in the tube, or any approximate correction for slight errors in such setting, two sources of considerable error and inconvenience, especially when the thread must be set near or under a line of the graduation. And, lastly, the total time of calibration for a result of given accuracy is reduced to one half or one third of that required by Neumann's method, the quickest and most satisfactory with which I am acquainted, except that given by Pickering. The latter, described with some slight inaccuracies at the reference noted below, is a neat application of the graphical method, and the curve of lengths of thread adopted in the method which I have described is identical with the corresponding one given by Professor Pickering, while the whole process is fully one third shorter and somewhat more accurate. From a series of calibrations executed upon the same thermometer (one with a millimetre scale by Baudin of Paris), using a variety of methods, I have obtained slightly more concordant results with the proposed method than with Neumann's or Pickering's, all three possessing, however, nearly the same degree of precision, and decidedly better results with these than with any of the other existing simple methods.

Considerable aid in eliminating errors of parallax in such work is sometimes found by looking down upon the horizontal thermometer through a vertical tube having a small hole at each end. One of the cheap French microscopes with its lenses removed, and inverted in its stand, answers this purpose well. With such a device two calibrations of the above described thermometer with threads of 3 cm. and 5 cm. respectively, each with only one series of observations, and requiring not more than one hour and a half each for completion, gave results whose average difference from each other at nine points was 0.04 mm., and the arithmetical sum of the extreme differences was 0.12 mm., a result of sufficient accuracy for any class of work of which such an instrument is capable.

For brief descriptions of methods of separating threads of mercury for calibration, reference may be made to the paper by Russell and the text-book by Pickering noted below. These processes are in general use, and are safe and convenient.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
Boston, Feb. 1st, 1882.

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